The foundation is rotting and the basement is flooding: A deeper look at the implicit trust relationships in your organization

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Who am I?

- Senior security researcher at Assured Information Security
  - Leads Denver, CO office
  - Leads the low-level computer architectures group
  - Plays in:
    - SMM
    - VMM
    - BIOS
- LangSec Cultist
- Avid outdoorsman/fitness nut

Outline

- Introduction
- Background
  - Threat modeling
  - Low-level attack surface
  - Technical Debt
- Who you trust, and don't realize you're trusting
  - Mapping your trusted computing base (TCB)
  - An example of pivots
  - Less is more
- Selling InfoSec
  - Win themes
  - "InfoSec debt"
- Conclusions

Introduction

- Information security is always seen as a cost to doing business, not a way to help achieve business goals

- I have been collaborating with a number of CISOs/Dir. Of IT Security in recent months and provide an “adversarial mindset”

- By bringing an attacker’s perspective to the table, you can identify threats to business and provide a better ROI
  - Focus on supporting business, not Infosec as be-all, end-all

Background: Threat Modeling

- "Chess vs. Poker"
  - – InfoSec research focuses on elegance
  - – Attackers and users of technology focus on ease-of-use/convenience or ROI
- As InfoSec researcher/professional
  - – I am rewarded for "neat tricks" and elegant exploits – synthetic/fabricated environments
  - – You are rewarded for deploying solutions and new defenses – not making things more "secure"

Background: Threat Modeling II

- Everyone who uses technology is an information security practitioner: “cyber civilians”
  - – Just want to accomplish their goal
- Attackers are motivated by ???
  - – Money? – The easiest way to make money will provide **highest ROI – just like you!!!**
  - – Revenge? – Their goal is destruction, not hiding their tracks
  - – Fun? – Aims for soft targets and moves on

Background: Technical Debt

- Metric used to track growing gap between product in reality and in a “perfect world”
  - If you accept no technical debt, you will get to market late
  - If you take on too much technical debt, your product will be unstable and impossible to maintain
- Helpful concept to sell product investors on development
  - A little more $ now will save $ later
  - Maintenance over life-cycle may outstrip initial development costs if too much technical debt is taken on

Background: Trusted Computing Base (TCB)

- The body of code that executes as part of “privileged” container
- Privilege can be defined as:
  - Administrator privilege
  - OS/Kernel privilege
  - Hypervisor privilege
  - Access to sensitive data ← commonly overlooked!
  - Humans with access
- Goal: Shrink this as small as possible
- Measure/protect this codebase as other code running will not be able to access sensitive data…

Mapping the TCB

- Unfortunately, this is extremely hard?
- Example: Intel legacy boot process
  - BIOS is loaded from ROM into RAM ← **BIOS vendor**
    - Generally hashed and checked
  - BIOS loads ISA/PCI option ROMs off of devices
    - Video card ← **GPU vendor**
    - NIC ← **NIC vendor**
    - RAID controller ← **RAID vendor**
  - BIOS loads OS from disk ← **OS vendor**
    - Can be hashed and checked
    - Could be run under virtualization ← **Hypervisor vendor**
- You are trusting each of these vendors before your application is even run!

Mapping the TCB II

- Now that your application is running:
  - Libraries/tool-kits you link against
  - Drivers for every device you install
    - Plug in a USB device, run a driver wrote by vendor or individual!
  - Everything running with more privilege than your application:
    - Anti-virus solution
    - DLP
    - OS
    - Hypervisor
    - BIOS/firmware
- A bug in any of these could be the entry point for attacker!
  - Or consider a malicious developer at XYZ corporation adds back-door to your printer driver!
- Do you vet these vendors via typical vendor evaluation process?

Background: Low-level attack surface

- Next couple slides show a few low-level attack at x86 architecture level
- Unlikely to be used against your organization
- Highlight that there is always a way in for a sufficiently determined attacker
  - If you've got one of those, you are already failing
- You want to ensure your organization is not the target of a sophisticated attacker

Background: Low-level attack surface

- Stepping p3wns(2013) – A. Cui et al.
- Showed that pivoting through printer would allow remote shell from behind firewall
- Just by printing a document, printer was infected
- Could infect IP phones and smart switches for stronger foothold into network

Background: Low-level attack surface

- Extreme privilege escalation on Windows 8/UEFI Systems (2014) – C. Kallenberg et al.
- Showed that the reference implementation for most modern systems' firmware was vulnerable
- Most firmware vendors copied reference implementation
- Could escalate from user application to firmware

Background: Low-level attack surface

- MoRE Shadow Walker (2014) – J. Torrey
- Showed that x86 hardware could be misused to hide malware from OS protections and anti-virus
  - Bypass anti-kernel patching
  - Anti-virus could not detect modifications to code
- Split view of memory data vs. code
  - Reading memory gives different output than executing it
  - No way to measure what is running

Virtual Memory Security

- **Paging/virtual memory is a protective feature/ promise**
  - First code in will be able to control system – usually BIOS/OS
- **Unless you can access the pages tables, you are locked out (until now)**
  - Can't add mappings to page tables unless you have a mapping to the page table
- **Protects against certain classes of attack**

Cluck Cluck Goal

- **Goal: Map in arbitrary physical memory**
  - Requires modifying page tables – need to know where they are in virtual memory
- **Can be kernel shell-code, live memory forensics, etc.**
- **Have ring-0 access, but confined to OS-controlled mappings**
  - Cannot access MMIO devices for example
- **OS independent**

Problem

- **Only know where in physical memory (CR3) the page tables are**

- **Cannot map in the page tables without having the page tables mapped in already**
  - The OS usually has a hard-coded value (0xC0000000 in many Windows systems)
  - OS-specific attacks are lame, let's exploit the architecture!

- **You do not know where your code is executing since you cannot access the page tables**

PCIe ECAM

- **Need control over just 32-bits of memory at a known physical address**
  - This is the crux
  - Can bootstrap a recursive mapping

- **Enhanced Configuration Access Mechanism**
  - PCIe has more configuration space per device
  - Port I/O is slow
  - Need a way to access it faster

- **ECAM shadows device configuration space into physical memory**
  - Base address is stored in PCIEXPBAR register

Solution

- **Construct a PDE that maps in the page directory (recursive entry)**
  - Use the CR3 physical address and mark it as present/RW/PS

- **Utilize Port IO to insert new PDE into PCI configuration space**
  - We have just modified what the CPU thinks is physical memory through port IO!

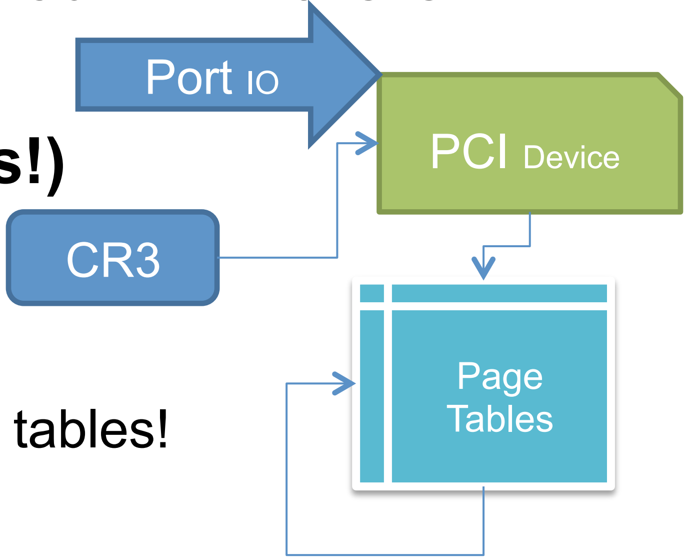
- **Determine physical location**
  - MCH stores the PCI base address in a configuration register (port IO again!)

Solution II

- **But where can our PDE go?**
  - Can’t trash random registers or system may crash!
- **Thank you Intel for the SCRATCHPAD DATA register**
  - “This register is for software use, it has no functionality”
  - 32-bits of beautiful storage right in the MCH (D0:F0)
  - Port I/O access to physical memory, write that PDE!
- **Determine physical location**
  - MCH stores the PCI base address (PCIEXBAR) in a configuration register (port IO again!)

Solution III

- **Change CR3 to point to PCI configuration space**
  - Kernel code is marked as Global, thus the TLB will cache the code segment, so the box won't crash
  - The CPU doesn't know that it's doing anything wrong (using PCI config like this is wrong) and the MCH doesn't know how the CPU is using the memory!!!
- **Scan the 'real' page directory (we know where it is now) for an empty entry and put our PDE there**
- **Switch CR3 back (yes this works!)**
- **Profit! All in a few lines of ASM**
  - You have a virtual pointer to the page tables!



Caveats

- **Alignment – PDE and CR3s are not aligned, requires some bitwise operations**
- **Needs PCI registers that are OK to be trashed (like the MCH's scratchpad register)**
  - There are plenty of options on modern systems
- **This technique requires Ring-0 and global pages**
  - Can be done from ring-3 with IOPL

Design Flaws

- Classic case of feature creep
- PCIe ECAM is for higher performance
- Violates assumptions
- This has happened before
  - SMM caching bug
  - Virtual Machine side-channels
  - Etc…

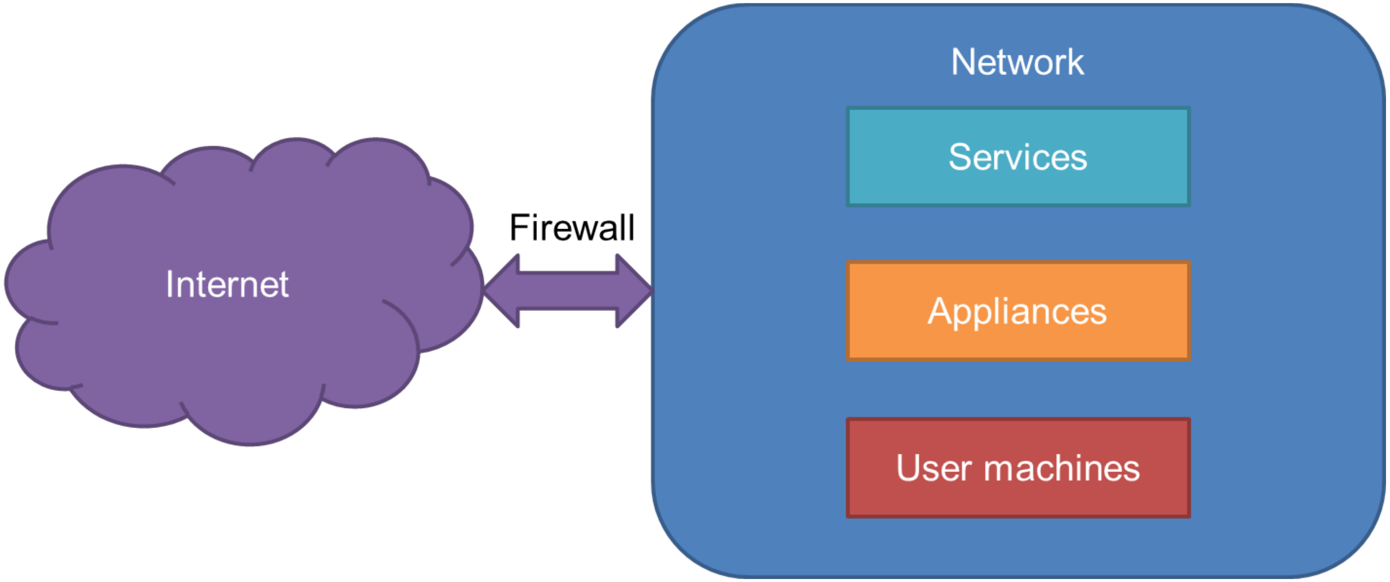
Pivots in an attack

- Attackers are lazy
  - Aim to accomplish goals as easily and quickly as possible
  - Easier to attack a legacy service running under an employee's desk than fully patched and firewalled server in NOC
- Will aim for soft targets first, perform recon of network, and pivot to goal systems
  - May happen multiple times
- Most organizations focus on perimeter defense
  - Hard exterior with a soft, gooey filling (vendors!!!)
  - Once perimeter has been breached, game over

Less is more

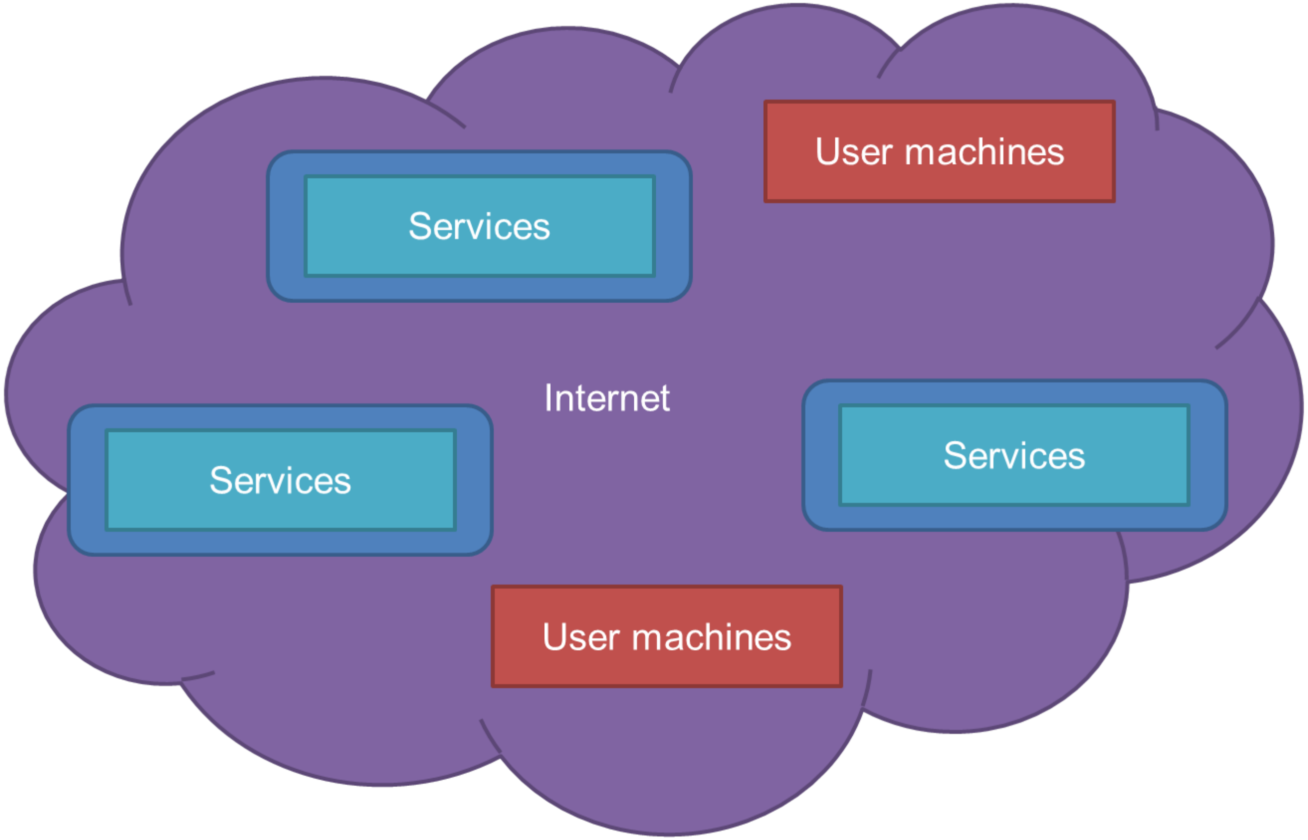
- The less you have in your network's TCB, the better!

- Hosting on the cloud (or with cloud model) can de-privilege your organization's network
  - Move from this:



Less is more

- To this:



Less is more

- You have now de-privileged the majority of your organization!
  - Least privilege principle
- Shrinking TCB to only include the cloud applications
- Penetrating your organization’s office network much less beneficial to attacker
  - OSINT less valuable
- Less trust of unknown entities (other than cloud provider)

Selling InfoSec

- Million dollar question (literally!):
  - How do you communicate the value-add that security brings to an organization when it is constantly seen as a cost
- Need:
  - Common language to speak to other organizational stakeholders
  - Holistic view of threats and adversary
  - Metric(s) to track progress and ROI
  - Knowledge of when enough is enough

Selling InfoSec: Win Themes

- Need to steer dialogue towards positive: create “win themes” for your security practice
- By implementing less is more, can slim operations and minimize costs in long-run
- Why? You as CISO/defender are the most impacted in breach
  - Company: A-OKAY!
  - Customers: Grumble, but OK
  - You: Checking out indeed.com

Selling InfoSec: Model of Adversaries

- In order to properly protect your organization, you need to know what from:
  - Low-hanging-fruit attackers (automated, script kiddies, etc…)
  - Everyday thieves (looking for profit, don’t care about your company in particular)
  - Advanced, targeted threat (targeting your company, invested in successful exploitation)

Selling InfoSec: Model of Adversaries II

- This is not “threat intelligence”, or pen-testing
  - Different goals

- This is looking at your organization and imagining your adversary’s incentives
  - Are you one-of-many or do you stand out
  - What motivates them, and how do you shift their behavior?

Selling InfoSec: Model of Adversaries II

- Know your organization is not monolithic
  - By implementing least privilege principle and breaking network into logical units that are mutually untrusting you may find savings
- Research competitors to compare
  - When running from a (non-targeted) bear, you only need to outrun the other guy, not the bear!

Selling InfoSec: Metrics

- You cannot sell something you cannot measure!
- Metrics **must** be understandable to all stake-holders
- "InfoSec Debt" – Use similar model to translate technical details into a fiscal model that is easy to align with business goals
  - Remember you are there to support the business goals!

Selling InfoSec: InfoSec Debt

- Inventory network
  - Each device is a risk, remember the implicit trust in unknown entities that each device brings
  - Each device has a maintenance cost: patching, IT support, monitoring, log data
- Inventory data
  - Data can be a liability if breached
  - “Crown jewels” are worth a substantial % of company value

Selling InfoSec: InfoSec Debt II

- Predict costs out 1, 3, 5 years
  - Just like technical debt, costs over time could exceed short-term savings
    - Ex. Product A costs $10,000 more, but automatically is patched and doesn't open ports for debugging, Product B is cheaper, but will require specialized attention over its lifetime.

- Find balance between security and usability
  - No InfoSec debt = a turned-off computer in a safe

Selling InfoSec: InfoSec Debt III

- How much debt is too much? Too little?
  - Never invest more than your data/network is worth
  - Will you save more technical debt at the expense of business goals? Sometimes a worthy trade-off, now you can measure and compare apples to apples!
- Remember, just like normal debt, it grows over time
  - InfoSec Debt is variable rate:
    - Exploits make their way into kits
    - Automated scanners can detect your weaknesses
    - Maintaining a legacy appliance gets more costly as it stops being able to support new protocols/methods
    - Vendors stop patching old appliances (look at Android phones!)

Concluding Remarks

- A sufficiently determined attacker will be able to find a way into your network
  - Need to model risk & adversary and protect accordingly
  - If you're being specifically targeted, you're already failing
- InfoSec doesn't need to only be a cost
  - Can provide an ROI
  - Bolster brand
- Measuring and tracking "InfoSec Debt" allows you to defend security costs to organizational stakeholders
  - Track progress and improve buy-in
  - Compare vendors objectively

Questions

- **Thank you**

- **Any questions?**